AS Unit 1: Basic Biochemistry and Cell Organisation

Name:	Date:

<u>Topic 1.1 Chemical Elements are joined to form biological compounds</u> – Page 1 of 5

1.1 Chemical Elements are joined to form Biological Compounds – from your syllabus

(a) the key elements present as inorganic ions in living organisms: Mg^{2+}, Fe^{2+}, Ca^{2+}, PO_4^{3-}

(b) the importance of water in terms of its polarity, ability to form hydrogen bonds, surface tension, as a solvent, thermal properties, as a metabolite

(c) the structure, properties and functions of carbohydrates: monosaccharides (triose, pentose, hexose sugars); disaccharides (sucrose, lactose, maltose); polysaccharides (starch, glycogen, cellulose, chitin)

(d) alpha and beta structural isomerism in glucose and its polymerisation into storage and structural carbohydrates, illustrated by starch, cellulose and chitin

(e) the chemical and physical properties which enable the use of starch and glycogen for storage and cellulose and chitin as structural compounds

(f) the structure, properties and functions of lipids as illustrated by triglycerides and phospholipids

(g) the implications of saturated and unsaturated fat on human health

(h) the structure and role of amino acids and proteins

(i) the primary, secondary, tertiary and quaternary structure of proteins

(j) the relationship of the fibrous and globular structure of proteins to their function

Learners should be able to use given structural formulae (proteins, triglycerides and carbohydrates) to show how bonds are formed and broken by condensation and hydrolysis, including peptide, glycosidic and ester bonds.
(Learners should be able to recognise and understand but not reproduce the structural formulae of the above molecules.)

SPECIFIED PRACTICAL WORK

- Food tests to include: iodine-potassium iodide test for starch; Benedict's test for reducing and non-reducing sugars; biuret test for protein; emulsion test for fats and oils

End of topic check list for BIOLOGICAL MOLECULES
Tick as appropriate:
RED : I do not know about this
AMBER: I have heard about this but have not learned this yet. I am unsure on this.
GREEN: I have heard about this and I have learned this. I am confident about this.

Topic	RED	AMBER	GREEN
1. Distinguish between the terms: atom, molecule, element, compound, organic, inorganic			
2. The most common elements in living organisms are hydrogen, carbon, oxygen and nitrogen.			
3. The role of magnesium, iron, phosphate and calcium in cell metabolism			
4. Water is essential since all reactions of life rely on water and key elements are found in aqueous solution.			
5. The importance of water in terms of its polarity, ability to form hydrogen bonds, surface tension, as a solvent, thermal properties, as a metabolite.			
6. Can differentiate between monomers and polymers			
7. Small molecules can be combined by condensation reactions and large molecules broken down by hydrolysis.			
8. Carbohydrates consist of carbon, hydrogen and oxygen with the general formula $(CH_2O)n$ and are monosaccharides, disaccharides (soluble, sweet) and polysaccharides.			
9. Monosaccharides are monomers named according to the number of carbon atoms: triose, pentose, hexose			
10. The structural formula may be a straight chain or a ring, as shown by glucose.			
11. Disaccharides are formed by joining two hexose units (as shown by sucrose, maltose and lactose). The bond formed between monosaccharides is a glycosidic bond.			
12. Glucose exists as two isomers (alpha and beta) and glucose forms different polymers; starch (amylose and amylopectin), glycogen, cellulose and chitin.			
13. Hydrogen bonding is important in maintaining the shape of biological molecules.			
14. Starch and glycogen are storage polysaccharides because glucose can be added or removed easily and they have little or no osmotic effect in cells because they are insoluble.			
15. Cellulose and chitin are similar structural polysaccharides with the alternating isomers allowing cross linking between chains (by hydrogen bonds), forming microfibrils (being laid down in different directions). In chitin second carbon –OH groups are replaced by amino groups.			
16. The elements which make up lipid molecules are carbon, hydrogen and oxygen plus phosphorus as phosphate in phospholipids.			
17. The main types of lipids are described as either oils or fats, depending on their melting points. They are immiscible with water but soluble in some organic solvents. Their functions include insulation, energy storage, and protection.			
18. Understand the structure of triglycerides and the			

structural formula for glycerol and general formula for a fatty acid. Be able to identify an ester bond. Unsaturated fatty acids contain double bonds.			
19. Lipids are used, rather than carbohydrates, as an energy store in seeds and animals because of a high yield of energy per gram.			
20. The products of lipid hydrolysis are fatty acids and glycerol.			
21. The components of phospholipids are glycerol, fatty acids and a phosphate group.			
22. Glycerol is hydrophilic and fatty acids hydrophobic			
23. A high intake of fat, notably saturated fats, is a contributory factor in heart disease.			
24. Able to draw the general formula for amino acids and recognise amino (basic) and carboxylic (acidic) groups.			
25. Proteins are polymers of amino acids of which there are twenty types which differ by the R group. Can identify amino acid structure, given a structural formula and a suitable table showing -R groups.			
26. Polymerisation occurs by condensation, to form peptide bonds giving rise to dipeptides and polypeptides. Can complete a diagram showing condensation, given the structural formula of an amino acid and label the peptide bond.			
27. Proteins show a primary, secondary, tertiary and quaternary structure.			
28. Primary is the type, number and sequence of amino acids linked by peptide bonds only.			
29. The most common secondary structure is an alpha helix formed by hydrogen bonding between the peptide bonds in the polypeptide chain.			
30. The tertiary structure is the folding of the alpha helix, as shown by globular proteins, to form very specific three-dimensional shapes.			
31. Projecting from the helix are -R groups which may interact to form bonds which help to maintain the tertiary structure's three dimensional shape.			
32. Able to identify disulphide, ionic, hydrogen and hydrophobic bonds between -R groups.			
33. The quaternary structure is where two or more polypeptide chains in tertiary form combine to form complexes joined by bonds similar to those in tertiary structure. Only some proteins, such as haemoglobin, exhibit quaternary structure			
34. Proteins can be classified according to function which is determined by structure: globular proteins function as enzymes, antibodies and hormones; fibrous proteins such as keratin and collagen have alpha helices linked into strands.			

I. **Introduction** - **Chemical terms and Elements**

		Completed
1.	Read the following: • Rowlands p20 • Toole p • Hand out 1.1a Minerals in cell metabolism • Hand out 1.1b Bonding	
2.	Read and complete 1.1b	
3.	Look at the PPT 1.1 and then complete the following: • Give definitions for the terms organic and inorganic • What is an element? Give examples to help illustrate your answer • What does the term atom mean – make a drawing to support your answer. What is the difference between an atom and ion? • Distinguish between the terms molecule and compound.	
4.	Monomers are small molecules, which may be joined together in a repeating fashion to form a larger, more complex molecule called a polymer. All living organisms are primarily made up from 5 classes of biological molecule: Lipids, Water, Carbohydrates, Proteins and Nucleic Acids. Complete table 1 on the next page.	
5.	Complete the table 'Chemical Definitions' on the following page. You will need to place marks in the appropriate columns, some items may require more than one tick.	
6.	Read and complete pages 6 and 7. This covers the role of minerals and the main elements found in biochemical groups.	

Table 1 Monomers and Polymers in Biological Compounds

Biological Compounds	Does it have monomers and polymers	General name of monomer	General name of polymer	Other Notes
Proteins	Yes	Amino acid	Polypeptide	
Water				
Carbohydrates				
Nucleic Acids				
Lipids				

Table 2 Chemical Definitions

Substance	Atom	Ion	Molecule	Compound	Element	Organic	Inorganic
NaCl			X	X			X
H_2O							
$C_6H_{12}O_6$							
Mg^{2+}							
Fe							
$H_2NCHRCOOH$							
CO_2							

Biological Molecules

Below is a diagrammatic representation of the organic molecules found in living organisms.

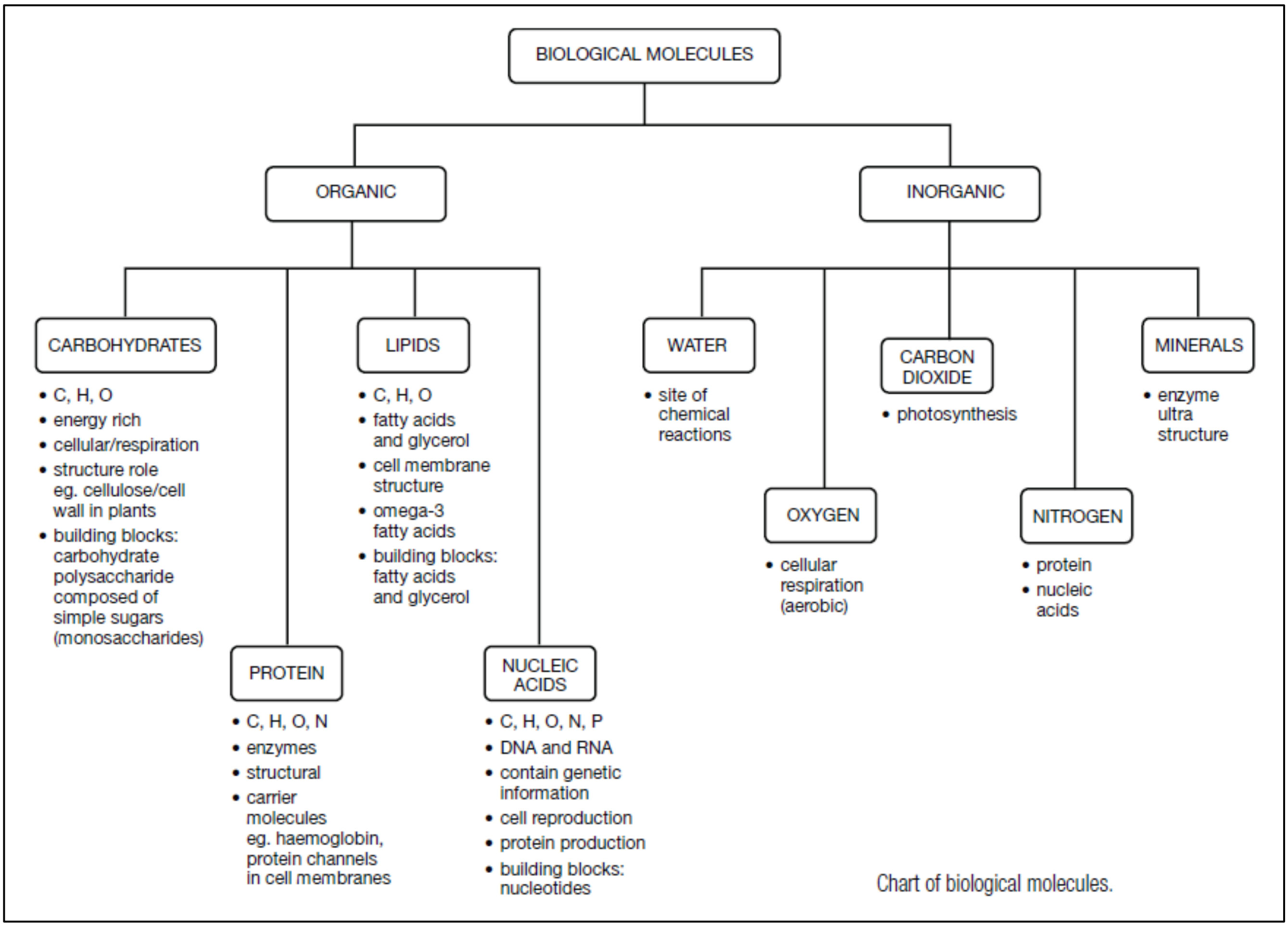
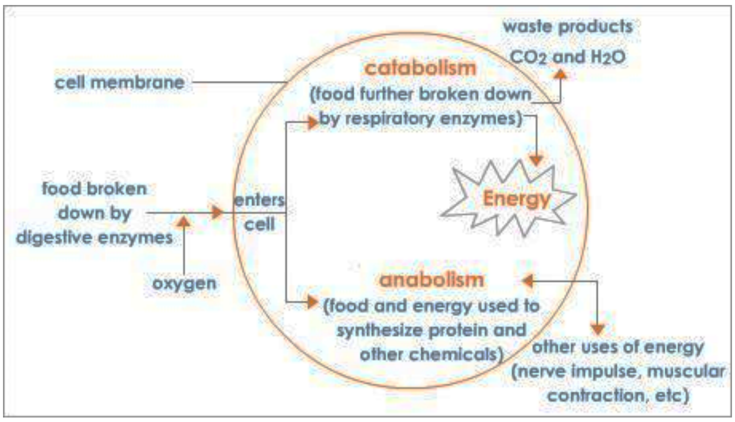


Chart of biological molecules.

Metabolism.
All organisms carry out complex chemical reactions. Enzymes govern all these reactions. The word metabolism is the sum of all of these reactions occurring in organisms.
There are two types of metabolism, building molecules up (anabolism) or breaking molecules down (catabolism.)
Put the following into the correct category.



Protein synthesis; digestion of food in the mouth; decomposition; photosynthesis; aerobic respiration; DNA replication; production of starch or glycogen.

Anabolism	Catabolism

Use your textbook to complete the table below:-

Class	Elements Always Present	Elements sometimes present
Carbohydrates		
Lipids		
Proteins		
Nucleic Acids		

Filling in the above table should back up the statement that the three most common elements found in living organisms are **carbon**, **hydrogen** and **oxygen**.

What is meant by the term metabolism?____

Use hand-out 1.1a Give two examples of the roles the following minerals play in metabolism:

Mineral	Role 1	Role 2
Iron		
Phosphate		
Calcium		
Magnesium		

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Minerals in Plants and Animals

Plants gain their minerals by direct absorption from the soil whereas animals gain their minerals via their diet. Although a wide range of mineral types are essential in both plants and animals, most examination boards only expect candidates to have a detailed knowledge and understanding of the uptake, transport and roles of nitrates, phosphates, magnesium and calcium in plants, and of the sources and roles of phosphates, chloride, calcium, iron, sodium and potassium in humans. Thus questions must be expected on these topics.

> ***Remember*** *- examiners may still set data interpretation and application questions on other minerals not specified in the syllabuses.*

Macronutrients and micronutrients

Macronutrients are minerals which are required in relatively large quantities. In plants they are nitrates, phosphates, potassium, calcium, magnesium, sulphur and iron. In animals they are phosphate, chloride, sodium, potassium, calcium, and iron.

Micronutrients are minerals (trace elements) that are required only in minute quantities. Intake of large quantities of them may be toxic and might cause illness and death. In plants they include zinc, copper, boron and molybdenum. In animals they include zinc, iodine, fluorine, copper, cobalt and manganese.

The roles of minerals in plants

Table 1. shows the roles of some of the more important minerals in plants.

Uptake of minerals by plants

Minerals in the soil, existing within the soil particles, dissolve and ionise into the soil water thus making the soil solution. Minerals are similarly released from the microbial decay of soil dead organic matter (such as leaf litter and dead organisms) and from humus. Humus is the organic matter that has partially decayed so that it is amorphous (has no recognisable form).

Plants absorb the minerals from the soil solution, mainly via the root hairs. A small amount of absorption probably occurs over other areas of the root surface, such as via the piliferous layer cells between the root hairs.

The ions in the soil solution enter the plant by both passive and active transport. **Passive transport** involves the **apoplastic pathway**. This is the system of continuous cellulosic cell walls from the surface piliferous layer to the endodermis. These walls contain water and dissolved ions which can flow from the soil to the endodermis, via the cellulosic walls, under the pull of the transpiration stream.

Table 1. Roles of minerals in plants

Mineral	Roles
Nitrate*	Reduced to nitrite by **nitrogen reductase** during **amino acid synthesis**. Used in the synthesis of proteins, nucleic acids, chlorophyll and many coenzymes.
Phosphate*	Component of DNA and RNA and of energy carrying coenzymes, such as ATP. Component of phospholipids found in cell membranes.
Sulphate	Component of sulphur containing amino acids (eg. cysteine) and some proteins. Component of coenzyme A. Deficiency causes '**chlorosis**' (yellowing of leaves due to a failure in chlorophyll synthesis).
Magnesium*	Component of chlorophyll molecules. Deficiency causes '**chlorosis**' due to a failure to synthesise chlorophylls. Magnesium pectate is a component of the middle lamella of cell walls.
Calcium*	Calcium pectate is the main component of the middle lamella of cell walls. Deficiency results in stunted growth due to poor cell wall development.
Iron	Needed as a cofactor in chlorophyll synthesis. It is a cofactor for peroxidase enzymes, such as catalase. Deficiency results in '**chlorosis**' due to poor chlorophyll synthesis.
Zinc	As a cofactor for alcohol dehydrogenase required for anaerobic respiration. Deficiency causes leaf malformations in some plants.
Potassium	Required as a cofactor for some photosynthetic enzymes. Deficiency causes yellow and brown leaf margins and premature leaf death.
Molybdenum	Needed as a cofactor for the enzyme **nitrate reductase** which catalyses the reduction of nitrate to nitrite during amino acid synthesis. Deficiency causes a reduction in growth rate.
Boron	Needed as a cofactor during mitosis in meristems. Deficiency results in abnormal growth and death of shoot tips, 'stem-crack' in celery and 'heart-rot' of beet.

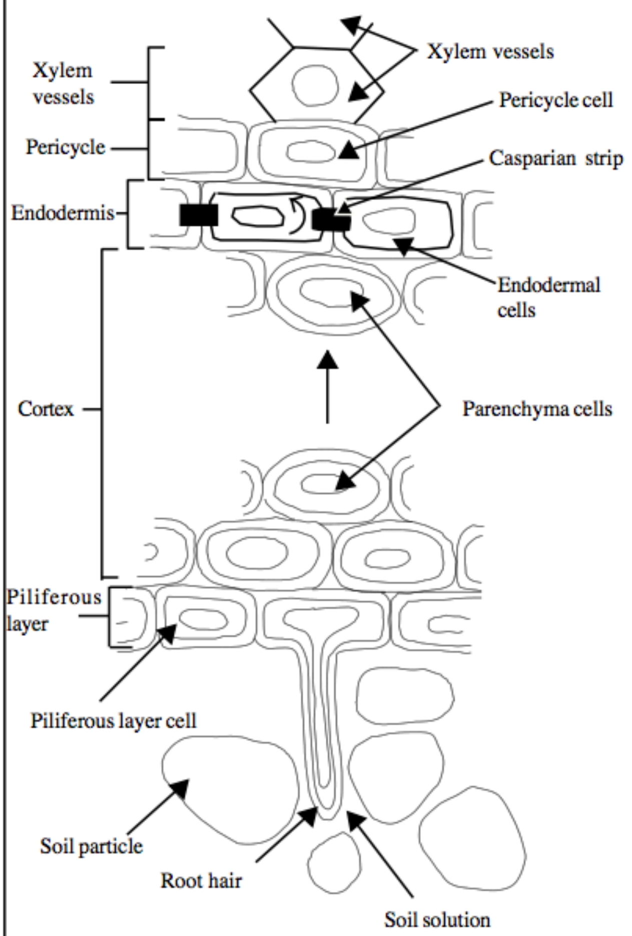
* specifically named on most syllabuses.

The water and ions of the soil solution enter the cell walls of the root hairs and piliferous layer cells by mass flow and by diffusion. The water and ions are eventually drawn up the xylem vessels to the leaves, stem and flowers. This maintains the gradients causing uptake of water and salts from the soil. This method of mineral uptake does not require an energy input from respiration and does not discriminate in the type of ions it absorbs.

Active transport occurs from the soil solution into the root hair cells. It also occurs into the cortex parenchyma cells from the solution in the apoplast pathway. These uptakes require the expenditure of respiratory energy in the form of ATP and are selective.

The plasma membranes and tonoplasts are differentially permeable and so only allow certain molecules in specific quantities through into the cytoplasm and vacuole. The cell membranes contain specific carrier molecules which give them their selectivity. Active transport also enables the minerals to be accumulated against the concentration gradient. The ions can then be passed from cell to cell, without having to cross further cell membranes, by simple diffusion across the **sympastic pathway**. This is the system of protoplasts across the cortex which interconnect by strands of cytoplasm, joining from cell to cell through pores in the cell wall. These strands of cytoplasm are called **plasmodesmata**. Fig 1. shows the structure of the root hair and cortex.

Fig 1. Transverse section through the root cortex in the piliferous (root hair) zone



Casparian Srips

Note in Fig 1. that the radial walls of the endodermal cells are thickened with water-impermeable suberin called **Casparian strips**. These effectively block the apoplastic passage of water and salts through the cellulose walls to the pericycle cells (parenchymatous starch storing cells) and thus xylem vessels.

> ***Remember*** *– the salts coming through this apoplast pathway are the same as in the soil solution and have not undergone selective absorption.*

The endodermal cells can still pass water (by osmosis) and salts (by active transport) through to the pericycle and xylem via the symplast pathway (through cytoplasmic plasmodesmata). Thus water and salts can pass from the apoplastic path into the cytoplasm and vacuoles of the endodermal cells, as it does into the parenchyma cells across the cortex. The endodermis, by virtue of its Casparian strips, thus imposes selectivity on the salts that pass through to the pericycle and xylem. Once in the xylem vessels the salts are carried upwards in the transpiration stream.

The roles of minerals in humans

Absorption of salts from the diet

Absorption of minerals into the blood mainly occurs in the ileum (part of small intestine). Sodium ions are able to move through the epithelial cells by diffusion. They are also actively transported into the epithelial cells from where they can diffuse to the blood.

> ***Remember*** *– the carrier protein for sodium ions also has sites for carrying glucose and galactose. Unless all three sites are occupied the carrier will not work. A question about this has been used by one exam board.*

Chloride, iodide and nitrate ions passively follow sodium ions or may be absorbed by active transport. Calcium ions are actively transported under the control of vitamin D, calcitonin and parathyroid hormone. Other minerals, such as iron, potassium, magnesium and phosphate are also absorbed by active transport.

The regulation of calcium

The absorption of calcium ions (and phosphate) from the gastrointestinal tract requires the presence of **vitamin D** in its activated form. If active vitamin D is deficient then calcium cannot be absorbed and abnormalities may appear in the bones. In children this may cause **rickets** with the symptoms of stunted growth and bent limb bones. In adults it can cause **osteomalacia** where the bones become weak and fragile due to loss of calcium and phosphate.

> ***Remember*** *– vitamin D precursors are changed to inactive vitamin D in the skin when irradiated with sunlight. The vitamin D undergoes modification in the liver and then kidney before it becomes active.*

The thyroid hormone calcitonin lowers the levels of calcium and phosphate in blood by inhibiting breakdown of bone and promoting the uptake of calcium and phosphate into bone.

The hormone parathormone from the parathyroid glands has the following effects:

- it stimulates the activation of vitamin D.
- it promotes the absorption of calcium and phosphate from the gastrointestinal tract in the presence of vitamin D.
- it promotes the release of calcium and phosphate from the bone to the blood when required.

- it promotes the active reabsorption of calcium ions back to the blood in the kidney, but inhibits the reabsorption of phosphate so that it is excreted.

These actions of calcitonin and parathormone are under negative feedback control from the thyroid and parathyroid glands (not involving the pituitary). Table 2. summarises the sources and roles of some of the more important minerals in humans.

Suggestions for practical or project work

- **Water culture experiments**. Plants are grown in prepared culture solutions of known composition. One mineral is omitted from each culture solution so that the effect of its absence on the plant growth can be assessed.
- **Ringing experiments**. Cylinders of tissue can be cut away around the circumference of stems of rooted herbaceous or slightly woody plants. The cylinders could include the phloem tissue or the phloem and xylem tissue. The effects of these treatments on the aerial parts of the plant could be observed and explained.
- **Examination and analysis of autoradiographs from radioactive tracer experiments**. The uptake of ions by roots and transport through the plant will have been traced by allowing the plant to absorb radio-active isotopes of the minerals (placed in the soil) and photographing either the whole plant or sections of the plant. Such photographs are called autoradiographs and show the isotope positions by bright areas.

Table 2. Minerals vital to the body

Mineral	Comments	Roles
Calcium *	Found in milk, eggs, green leafy vegetables and shellfish. Absorption from gut depends on the presence of **vitamin D**. The balance of calcium between bone and blood is controlled by the hormones **calcitonin** (from thyroid gland) and **parathormone** (from parathyroid glands).	Component of bones and teeth. Cofactor for blood clotting. Required for normal muscle and nerve activity, cellular motility, exocytosis, endocytosis, chromosome movements in cell division and release of neurotransmitters. Deficiency of calcium could result in **rickets**. Pregnant women require extra calcium to enhance bone growth in the fetus and to prevent calcium transfer from maternal to fetal bone. Lactating mothers require extra calcium which is fed to the baby via the milk and used for bone growth.
Iron *	Good sources are meat, liver, egg yolk, beans, nuts, cereals, shellfish. Higher daily intakes are needed in pregnant women for synthesising fetal haemoglobin. Stored in liver, spleen and red bone marrow as **ferritin**.	66% of body iron is found in **haemoglobin** which is important in blood gas transport. It is also found in **myoglobin** which holds oxygen in muscles and in the **cytochromes** of the electron transport chain. It is required as a cofactor for peroxidase enzymes, such as catalase. Deficiency of iron could result in **anaemia**.
Sodium *	Found in most foods and added as salt to food. Excreted in sweat and urine.	Most abundant cation in extracellular fluid and affects water distribution by osmosis. Essential for nerve impulse conduction. Actively pumped out of cells by sodium pump.
Magnesium	Found in vegetables and most other foods.	Found with calcium in bones and teeth. Required as a cofactor for many enzymes, eg ATPase and hexokinase.
Potassium *	Found in most foods in required amounts. Much is excreted in the urine.	Most abundant cation in intracellular fluids. Essential for nerve impulse conduction and muscle contraction.
Phosphate *	Found in meat, fish, dairy products and nuts. Blood phosphate level is regulated by the hormones **calcitonin** and **parathormone**.	Component of bones and teeth. Provides a major buffer system in blood. Component of DNA and RNA and of energy carrying coenzymes such as ATP. Component of phospholipids found in cell membranes.
Chloride *	Found in most foods as component of salt (NaCl). Found in both extracellular and intracellular fluids. Much excreted in urine.	Involved in acid-base balance of blood and water balance. Required for HCl synthesis in stomach.
Iodine	Found in seafood, iodised salt, cod-liver oil and vegetables grown in iodine rich soil. Deficiency can result in **goitre** (swollen thyroid).	Required by thyroid to synthesize the hormones **thyroxine** and **tri-iodothyronine**. These hormones regulate metabolic rate and growth.
Fluorine	Added to domestic water supplies if natural levels are low.	Component of bones and teeth. Improves resistance to tooth decay and slows development of spinal osteoporosis.
Cobalt	Component of **cyanocobalamin** (Vit B_{12}). Found in liver, kidney, milk, eggs, cheese, meat.	Required for **erythropoiesis** (red cell formation). Deficiency could result in **pernicious anaemia**.
Zinc	Best source in meat.	Component of **carbonic anhydrase** in red blood cells and so important for CO_2 transport in blood.

*specifically named on most syllabusus.

Practice questions.

1. Suggest explanations for each of the following observations:
   (a) Prior to the Clean Air Act (1976) many children in atmospherically polluted areas of Britain suffered from rickets. 4

   (b) When a turgid plant is ringed to include the phloem the leaves above the ring remain turgid. Deeper ringing results in wilting of the leaves above the ring. 3

   (c) People living in areas where soils are iodine deficient may develop swollen necks. 3

   (d) As root hairs absorb positive ions from the soil they discharge equivalent amounts of hydrogen ions. 2
   (12 marks)

2. Suggest six precautions which should be taken when performing a water culture investigation of mineral nutrition in plants. (6 marks)

3. (a) The following statistics (hypothetical) refer to the iron balance of a healthy adult man.
   Daily iron requirement = 8.0 mg.
   Proportion of iron ingested that is absorbed into the blood = 60% (remainder lost in faeces).
   Proportion of iron absorbed that is used by tissues = 75% (remainder lost in urine).

   On a particular day a man obtained all his iron by only eating corned beef. This contains 2.9 mg of iron per 100 g of meat. Calculate the mass of corned beef that the man would need to consume to meet his daily requirement for iron. Show your working. 3

   (b) How does the body gain enough iron if the daily intake is deficient? 2

   (c) Milk only contains 0.1mg of iron per 100 g of milk which is less than a baby needs. Suggest how the development of anaemia may be avoided in babies. 2
   (7 marks)

4. Briefly explain why:
   (a) Calcium is important to animals and plants. 2
   (b) Some enzymes need metallic cofactors. 2
   (4 marks)

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Bio Factsheet

Number 78

Chemical Bonding in Biological Molecules

The contents of this Factsheet are directed towards AS level candidates. By studying this factsheet students should gain a knowledge and understanding of:
- **glycosidic bonds in carbohydrate structure.**
- **peptide bonds in polypeptide structure.**
- **ester bonds in lipid structure.**
- **hydrogen bonding.**
- **sulphur bonding.**
- **phosphate bonding.**

Introduction

Glycosidic, peptide and ester bonds are formed by a process called **condensation**. This is the joining of molecules by the removal of water and involves removing a hydroxide group from one of the molecules and a hydrogen from the other molecule. This type of reaction is important in synthetic processes. The reverse process, involved in digestion, is **hydrolysis** which is the splitting of molecules by the addition of water.

Glycosidic bonds

These are the bonds which join single sugars (monosaccharides) together to form double sugars (disaccharides) and multiple sugars (polysaccharides). The formation of a glycosidic link is shown in Fig 1.

By adding more alpha-glucose molecules on at positions X and Y the backbone molecules of starch(alpha-amylose) and glycogen may be built up. Alpha-amylose can be between 300 and 3000 alpha-glucoses long. The other component of starch is amylopectin. This is similar to alpha-amylose but is branched about every twentieth glucose by a **1,6 glycosidic branch link**. Glycogen has a structure similar to amylopectin but branches more frequently at about every twelfth glucose.

The reactive – OH group on carbon 1, labelled Y, is a reducing group and so gives the glucose reducing properties. (the power to donate hydrogen or electrons to other substances). In alpha-glucose this group is below the ring structure and during polymerisation forms **1,4 alpha-glycosidic bonds**. These can be hydrolysed by alpha-amylase enzymes, for example, salivary and pancreatic amylases in mammals and diastase in seeds, and so molecules such as starch and glycogen can be digested to maltose and then by maltase enzyme to glucose. The structures of alpha-amylose and amylopectin are shown in Fig 2.

> ***Exam Hint** - Candidates will be expected to recognise and name molecules and bonds but will not be expected to write down structural formulae from memory. Candidates may be asked direct questions about types of bonds, or may need to refer to the different bond types in essay answers.*

Fig 1. Formation of a glycosidic link

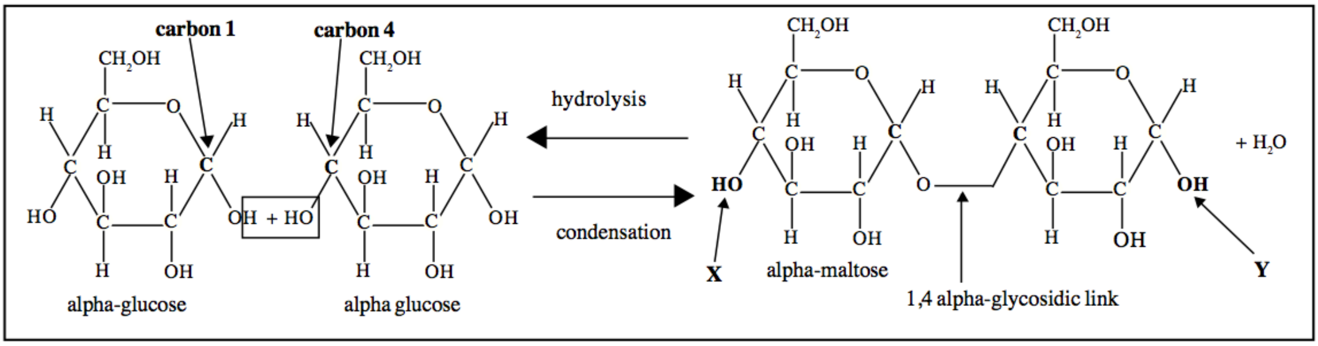
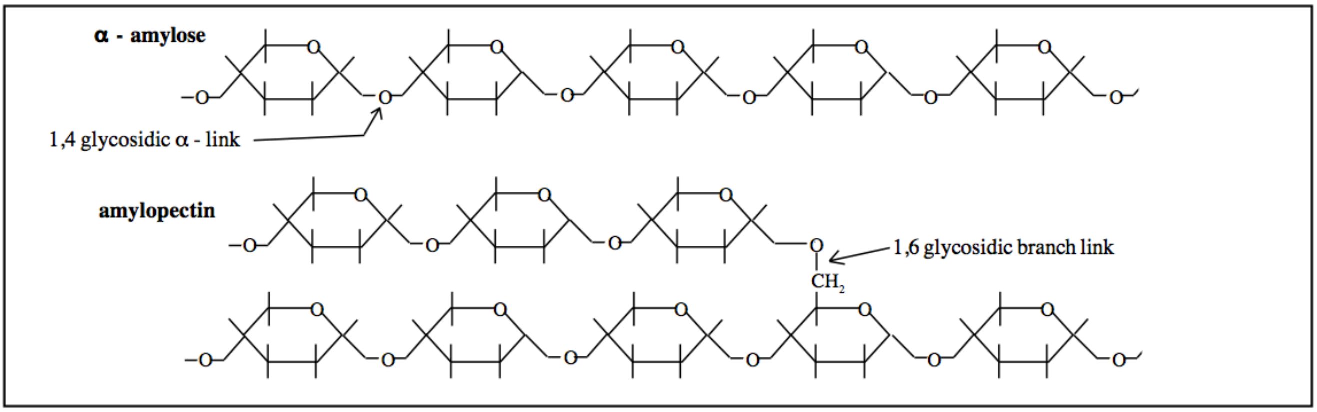


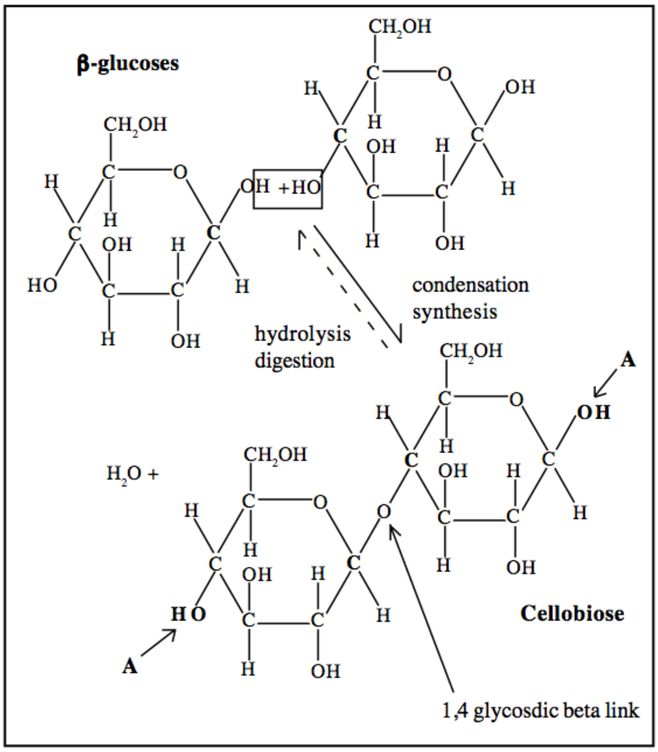
Fig 2. Structure of alpha-amylose and anmylopectin



Enzymes for breaking down the 1,6 glycosidic branch links are not present in most animals and so amylopectin (and glycogen) can only be digested by amylases down to the branch points. This leaves an indigestible residue of amylopectin, which is called dextrin. Cooking will hydrolyse the 1,6 glycosidic links and thus cooked starch can be completely digested.

In beta-glucose the reducing –OH group lies above the ring structure and when glycosidic bonds form they are **1,4 beta-glycosidic bonds (links)**. These are found in the structural compound, cellulose. The formation of a beta-link is shown in Fig 3.

Fig 3. Formation of a 1,4 beta-glycosidic link



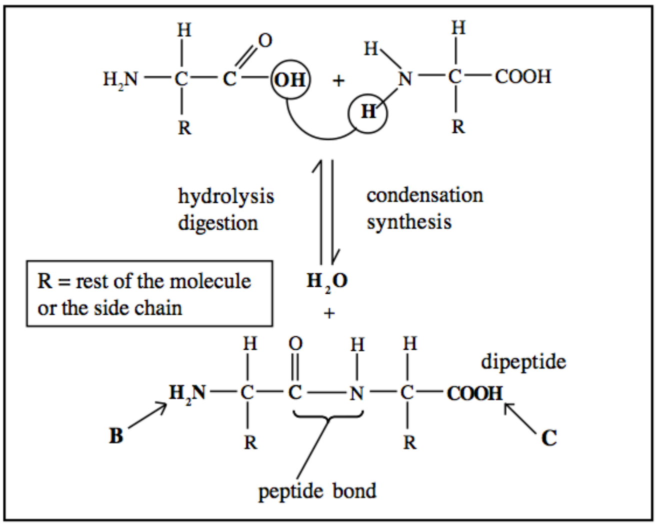
More beta glucoses can be added, on by condensation, to the disaccharide cellobiose at points A to build up a long unbranched cellulose molecule. Cellulose molecules run together in parallel fashion to form cellulose fibrils. Within a fibril the adjacent cellulose molecules cross link by **hydrogen bonds**. (Hydrogen bonds are described below). Individually such bonds are weak but their presence in large numbers gives strength which makes cellulose a good structural material in plant cell walls.

Very few animals possess cellulase enzymes capable of hydrolysing beta glycosidic links and so cellulose is usually indigestible. Many fungi and bacteria possess cellulases and are important in breaking cellulose down in rotting vegetation in the soil. The microbes in the rumens of cow and sheep also possess cellulases and so can break down the cellulose in the grass that these animals eat.

Formation of peptide bonds

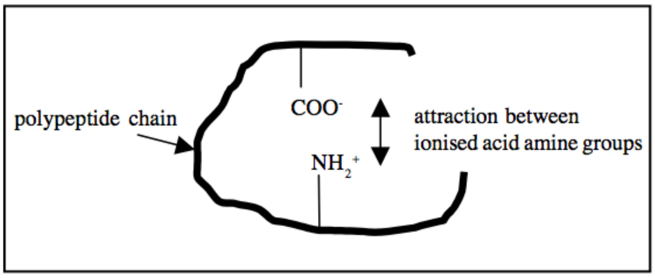
Peptide bonds are formed by condensation between the acid group of one amino acid and the amine group of another amino acid. They enable amino acids to be joined into long chains called polypeptides. Fig 4. shows the formation of a dipeptide from two amino acids.

Fig 4. Formation of a peptide bond



More amino acids can attach by condensation onto the amine group at B and the acid group at C so that a long chain of amino acids (a polypeptide) can be assembled. Polypeptides may be folded and cross-bonded into particular three dimensional shapes and assembled together into proteins. This involves **hydrogen** and **sulphur** bonds (described below) rather than peptide bonds. **Ionic attractions** may also be important in stabilising the three dimensional shapes of proteins. This is illustrated in Fig 5.

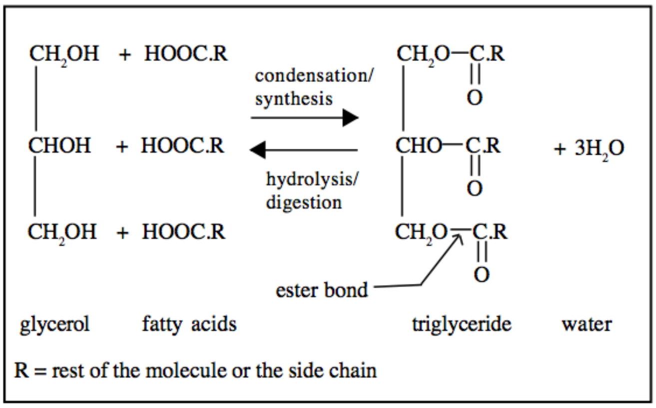
Fig 5. Ionic association (attraction) between two parts of a polypeptide chain.



Formation of ester bonds in lipid structure

An ester bond is formed by condensation between an acid and an alcohol. The main alcohol involved in lipid structure is glycerol (which has 3 alcohol or –OH groups) and the acids involved are fatty acids. Fig 6 shows the formation of a triglyceride.

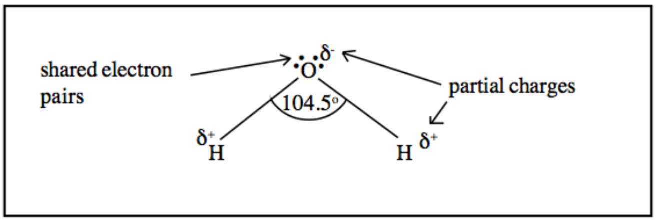
Fig 6. Formation of a triglyceride



Hydrogen bonding

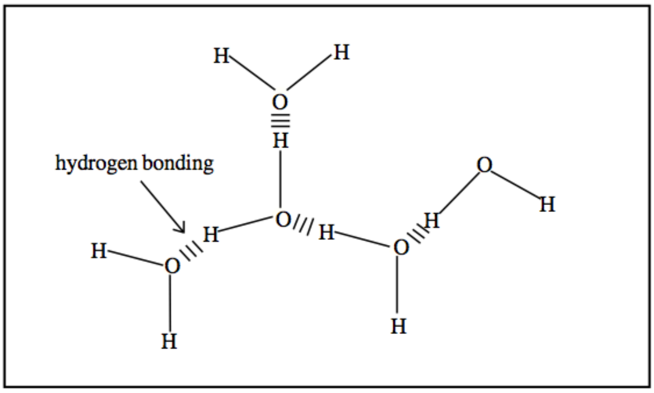
Water consists of two hydrogen atoms, each of which shares an electron with the single oxygen atom. These shared electrons (negative) lie closer to the oxygen than to the hydrogens (positive protons) and so the molecule becomes a charged dipole, with two partial positive charges at one end and a partial negative charge at the other end. This is shown in Fig 7.

Fig 7 . The water molecule



Because of these charges the hydrogen atoms of one water molecule are attracted to the oxygen atoms of adjacent water molecules. These attractions are called hydrogen bonds and are shown in Fig 8.

Fig 8. Hydrogen bonding between water molecules.

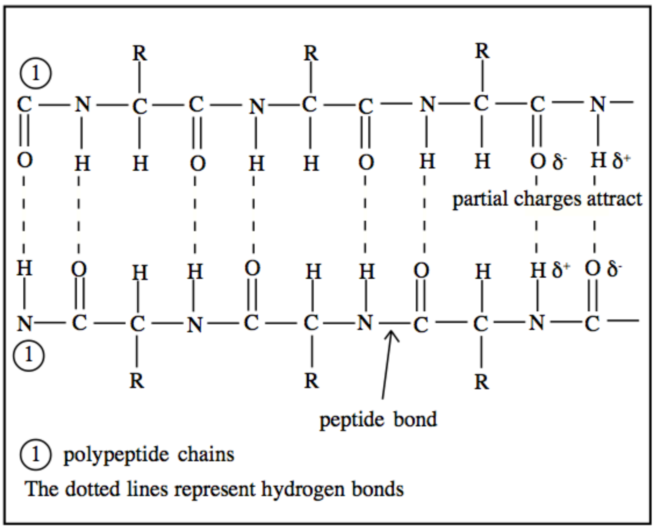


Hydrogen bonds occur between:

- parallel cellulose molecules holding them together in fibrils,
- opposite purine and pyrimidine bases holding DNA structure together
- polypeptide chains holding shape and protein structure together.

Fig 9 shows hydrogen bonds between nearby peptide bonds between two polypeptides.

Fig 9. Hydrogen bonding in polypeptides



Sulphur bonds

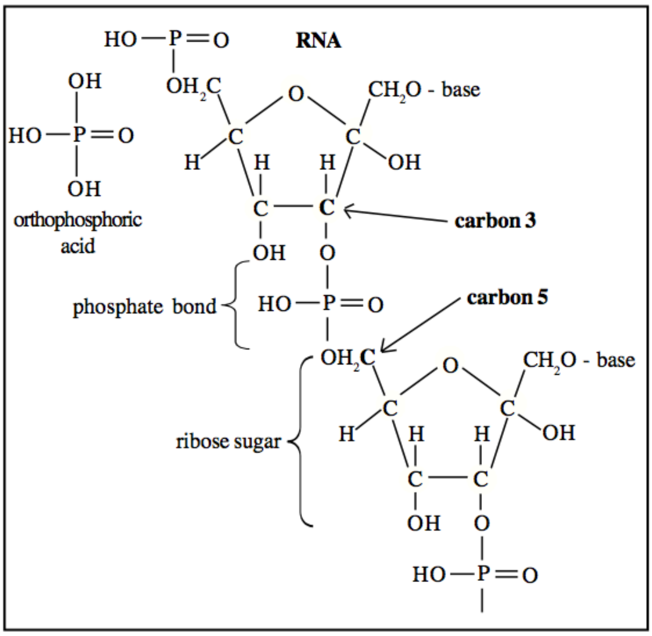
Amino acids such as cysteine and methionine contain sulphydryl (-SH) groups. The group has reducing properties since the H atom can be fairly easily removed. In proteins two nearby –SH groups may become oxidised (hydrogen lossed) forming a cross-linking sulphur bond (–S-S-).

Sulphur bonds are stronger and more heat stable than hydrogen bonds and so proteins that contain many sulphur bonds tend to have good stability. The RNA splitting enzyme, ribonuclease, for example, does not denature (break down) unless temperatures are raised to around 95 °C whereas most proteins denature above 42 °C.

Phosphate bonds

These are found joining the adjacent nucleotides in DNA and RNA structure. They are formed by condensations of orthophosphoric acid (H_3PO_4) between the –OH groups on carbon 3 of one pentose sugar and carbon 5 of the pentose sugar of the next nucleotide. This is illustrated in Fig 10.

Fig 10. Orthophosphoric acid and a phosphate bond in RNA



> ***Exam Hint*** *– Although examiners will not expect you to be able to write down structural formulae from memory, you will be expected to recognise molecular structures and to be able to manipulate molecules by joining them together with appropriate bonding.*

Practice Questions

1. The table below refers to some biological molecules and to the type of chemical bonds they contain. Complete the table by filling in the empty boxes. Some boxes may have more than one answer.

Molecule	Type of bond
	only 1,4 alpha-glycosidic
between nucleotides in nucleic acids	
in amylopectin	
	ester bonds
	peptide bonds
between polypeptide chains	
in glycogen	

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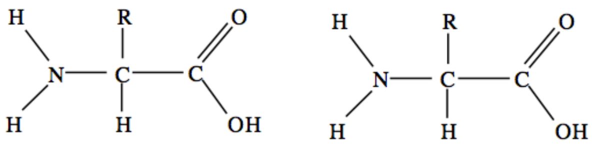
2. (a) Distinguish 'condensation' from 'hydrolysis'. 2

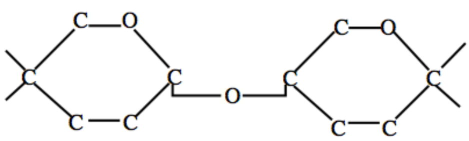
(b) The diagram below shows the general structure of two molecules of amino acid. Show how they would combine to form a dipeptide. 3



(c) (i) What is the name of the bond which joins together two adjacent amino acids? 1

(ii) Name three other types of bond involved in protein structure. 3

3. The carbohydrate below has been formed from two glucose molecules.



(a) What is this type of carbohydrate called? 1

(b) What is the name of the chemical bond which joins these two hexose units together? 2

(c) What is the chemical reaction in which one or more hexose units are joined together? 1

(d) (i) Draw a diagram to show how the two glucose molecules would have been bonded when forming part of a cellulose fibril. 1

(ii) Name the type of bond involved. 1

Acknowledgements;
This Factsheet was researched and written by Martin Griffin
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T 1 Condensation and hydrolysis

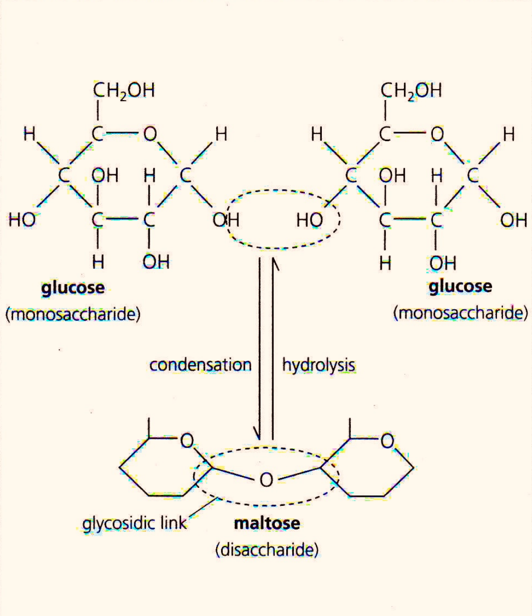
Many important biological molecules are polymers. Polymers are long-chain molecules made up of smaller molecules connected by chemical bonds. The smaller molecules are called monomers (Table 1). Polymers are sometimes called macromolecules (macro means large).

Table 1. Some biologically important polymers

Polymer	Monomer	Occurrence
protein	amino acids	all living things
starch	glucose	storage carbohydrate found in many plants
cellulose	glucose	structural carbohydrate found in plant cell walls
glycogen	glucose	storage carbohydrate found in many animals
DNA	nucleotides (composed of sugars, phosphates and nitrogen-containing bases)	genetic material

The chemical reaction that links monomers together to produce polymers is called a **condensation reaction**. Examples include glucose and fructose joining to make sucrose, and two glucose molecules condensing to form maltose (Fig. 1).

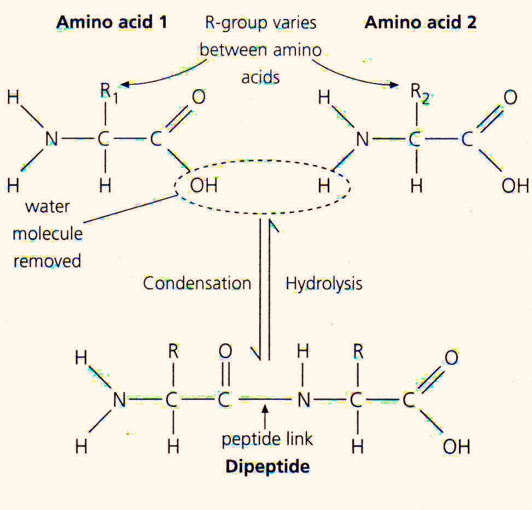
Fig. 1 Condensation and hydrolysis in carbohydrates



Hydrolysis is the reaction that splits a polymer into monomers. Examples include fat molecules being digested to give glycerol and fatty acids, and proteins being broken down to yield dipeptides and amino acids.

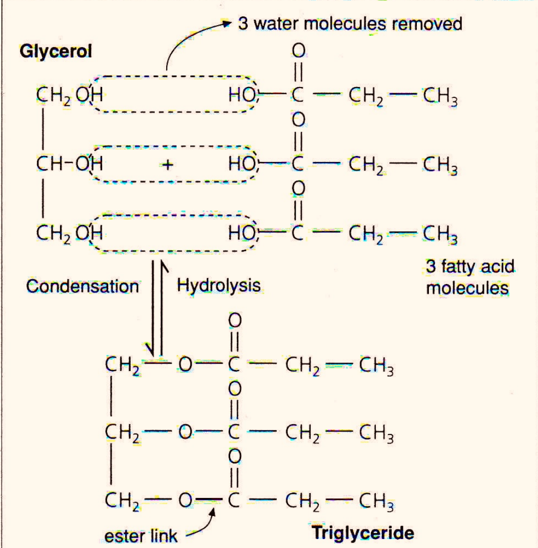
In protein synthesis, peptide links form between amino acids by the process of condensation (Fig. 2).

Fig. 2 Condensation and hydrolysis in proteins



In the synthesis of lipids, ester links are formed by condensation between the alcohol groups on a glycerol molecule and three fatty acids (Fig. 3).

Fig. 3 Condensation and hydrolysis in lipids

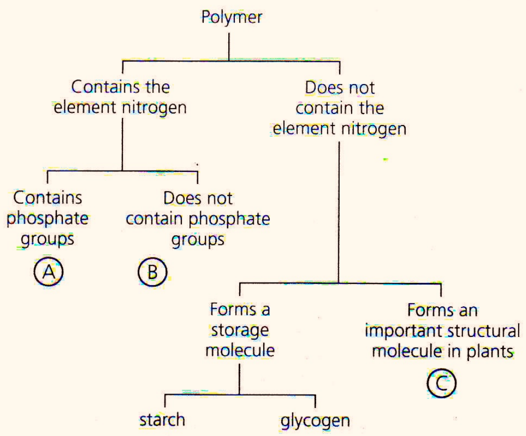


Questions

1 Copy and complete the table to show the effects of condensation or hydrolysis of the molecules named.

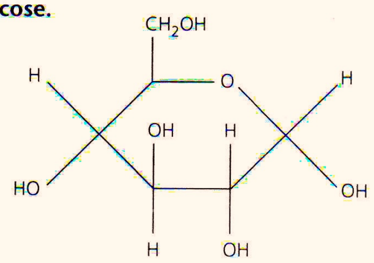
Molecule produced on condensation	Molecules produced on hydrolysis
DNA	....
....	amino acids
sucrose	....
....	glycerol and fatty acids

2 The diagram shows one way of distinguishing between some important biological polymers.



a Identify polymers A, B and C.
b Give one feature that could be used to distinguish between starch and glycogen.

3 The diagram represents a molecule of glucose.



a With the help of a similar diagram, show how two molecules of glucose may produce a molecule of maltose.

In producing glucose from starch, the term dextrose equivalent (D.E.) may be used.

$$\text{D.E.} = 100 \times \frac{\text{number of glycosidic bonds broken}}{\text{number of glycosidic bonds originally present}}$$

b Explain why starch has a dextrose equivalent of 0.
c Explain why pure glucose made from starch would have a dextrose equivalent of 100.
d What would be the value of the dextrose equivalent of maltose made from starch? Explain your answer.

4 Cellulose may be converted to glucose by two different methods of hydrolysis. Some of the differences between these methods are given in the table.

	Hydrolysed with acid	Hydrolysed by enzymes
Rate of hydrolysis	Rapid (minutes)	Slow (hours)
Temperature	200 °C	45 °C
Pressure	high	low
Formation of other products	likely	unlikely

a What molecules will be produced when cellulose is hydrolysed?
b Explain why the use of enzymes to hydrolyse cellulose is sometimes said to be more 'environmentally friendly' than the use of acid.
c Why is it less likely that other products will be formed when enzymes are used than when acid is used?